On Packet Marking Function of Active Queue Management Mechanism: Should It Be Linear, Concave, or Convex?

Hiroyuki Ohsaki and Masayuki Murata

Graduate School of Information Science and Technology, Osaka University, Japan

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Background

- AQM (Active Queue Management) mechanisms
  - Studied by many researchers
  - Supports the congestion control mechanism of TCP
- RED (Random Early Detection)
  - A representative AQM mechanism
  - Randomly discards an arriving packet
    - Keeps the average queue length small
    - Achieves high link utilization
  - Its operation algorithm is quite simple

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RED Known Problems

- Parameter sensitivity
  - Effectiveness is dependent on four control parameters (minth, maxth, maxp, wq)
  - Average queue length is dependent on traffic load
    - i.e., the number of active TCP connections
- Parameter tuning difficulty
  - The optimal setting of control parameters is dependent on several factors
- More deeply understanding on RED is necessary

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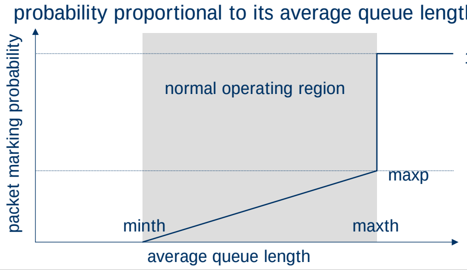
$$p_b = max_p \left(\frac{\bar{q} - min_{th}}{max_{th} - min_{th}} \right)$$

RED Packet Marking Probability

- RED randomly discards an arriving packet with a probability proportional to its average queue length



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Question on RED Packet Marking Probability

- Analytically known facts
  - TCP throughput is inversely proportional to p^(1/2)
    - p: the packet loss probability in the network
  - For M/M/1 queue, the average queue length is (rho/(1-rho))
    - rho: utilization factor
  - So, should the packet marking probability not be changed linearly to the average queue length?
- Question
  - *Whether the packet marking probability should be proportional to the average queue length or not?*

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Objectives

- Investigate effect of packet marking function on its performance
  - Steady state performance
  - Transient state performance
- Show how packet marking function should be determined
  - Utilize analytic results of TCP and RED steady state analyses
- Consider three classes of packet marking functions
  - Linear, concave, and convex
  - Show which packet marking functions is the best...
    - for good transient state performance and robustness

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Analysis Overview

- 1. Replace the packet marking function of RED with a generic function f(x)
- 2. Combine two analytic models
  - Stochastic model of TCP window size
  - Deterministic model of RED queue length
- 3. Analyze toward what value the average queue length converges...
  - for a given average queue length

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1. Replace Packet Marking Function and Define Queue Occupancy

- The packet marking function is replaced by

$$p_b = max_p f\left(\frac{\overline{q} - min_{th}}{max_{th} - min_{th}}\right)$$

- Introduce "queue occupancy"

$$x \equiv \frac{\overline{q} - min_{th}}{max_{th} - min_{th}}$$

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2. Combining Two Analytic Models

- Expected value of TCP window size: w(p)
  - b: the number of packets required for returning an ACK packet
  - p: the packet loss probability in the network

$$w(p) = \frac{1}{2}\left(\frac{W(p)}{2} + W(p)\right) = \frac{3\,W(p)}{4}$$

$$W(p) = \frac{2+b}{3b} + \sqrt{\frac{8(1-p)}{3bp} + \left(\frac{2+b}{3b}\right)^2}$$

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2. Combining Two Analytic Models (Cont'd)

- Queue length of RED in steady state: q
  - N: the number of TCP connections
  - w: TCP window size
  - B: maximum transmission capacity of RED router
  - tau: two-way propagation delay of TCP connection

$$\overline{q} = N\,w - B\,\tau$$

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3. Analyze Average Queue Length Convergence Point

- Average queue length convergence point: q(x)

$$\overline{q} = N\,w(p) - B\,\tau$$

$$= \frac{N}{4\,b}\left\{2 + b + b\sqrt{\frac{4 - 8\,b + b^2 + \frac{12\,b}{max_p\,f(x)}}{b^2}}\right\} - B\,\tau$$

- Queue occupancy in steady state: x^*

$$x^* = \frac{\overline{q}(x) - min_{th}}{max_{th} - min_{th}}$$

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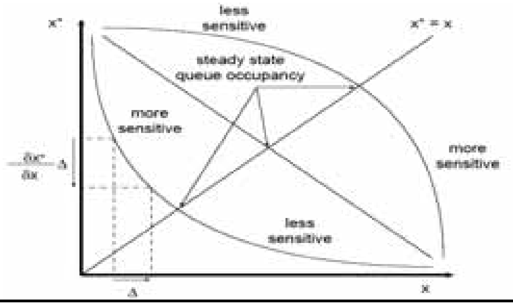
Effect of Packet Marking Function



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Optimal Packet Marking Function

- x^* becomes a linear function if f(x) is given by

$$f(x) = 12\left\{max_p\left(8-\frac{4}{b}+b\left(\frac{16a^2x^2}{N^2}-1\right)\right)-\frac{48ab\sqrt{max_p\,x\,C(1)}}{N}+36bC(1)^2\right\}^{-1}$$

- To optimize the steady state and transient state performances…
  - f(x) must be dynamically changed according to N
    - N: the number of active TCP connections
- However, the above function is impractical since…
  - RED has no capability to know the number of TCP connections
- Question
  - *For practical purposes, what type of packet marking function is the best for steady state and transient state performances?*

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Three Packet Marking Function Classes: Linear, Concave, Convex

- Linear $\mathcal{F}_\phi(x) = x^\phi$
- Concave $\mathcal{G}_\phi(x) = \left(1-\sqrt{1-x^2}\right)^\phi$

$$\phi \geq \lim_{x\to 0}\frac{-1+\sqrt{1-x^2}+x^2\sqrt{1-x^2}}{x^2\sqrt{1-x^2}} = \frac{1}{2}$$

- Convex $\mathcal{H}_\phi(x) = \left(\sqrt{1-(1-x)^2}\right)^\phi$

$$\phi \leq \lim_{x\to 0}\frac{2-2x+x^2}{1-2x+x^2} = 2$$

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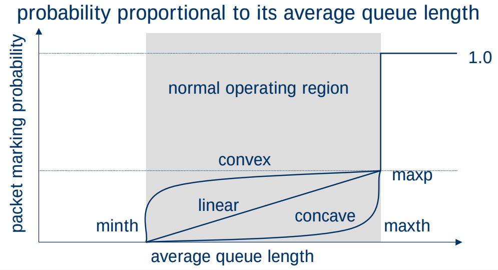
$$p_b = max_p\left(\frac{\bar{q}-min_{th}}{max_{th}-min_{th}}\right)$$

RED Packet Marking Probability

- RED randomly discards an arriving packet with a probability proportional to its average queue length



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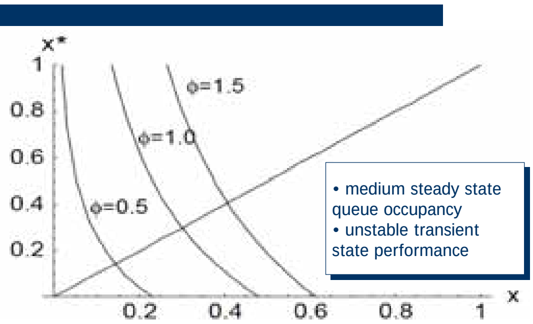
RED Queue Occupancy (Linear Case)



- medium steady state queue occupancy
- unstable transient state performance

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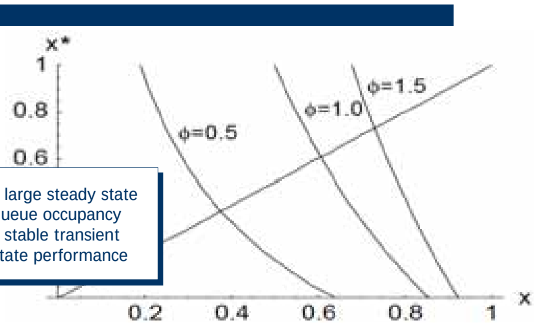
RED Queue Occupancy (Concave Case)



- large steady state queue occupancy
- stable transient state performance

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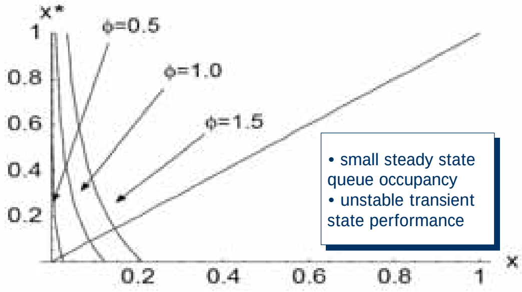
RED Queue Occupancy (Convex Case)



- small steady state queue occupancy
- unstable transient state performance

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Conclusion

- Analyze effect of packet marking function on RED's performance
  - Steady state performance
  - Transient state performance
- Show how the packet marking function should be determined
  - Utilize analytic results of TCP and RED steady state analyses
  - Derive the optimal packet marking function
- Consider three classes of packet marking functions
  - Linear, concave, and convex
  - Show RED with concave packet marking function is the best…
    - in terms of good transient state performance and robustness

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